Physics-informed Fully Connected and Recurrent Neural Networks for Cardiac Electrophysiology Modelling

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Atrial fibrillation (AF) is the most common cardiac arrhythmia, with a worldwide prevalence of 38 million cases. However, the mechanisms of AF are poorly understood, and the success rate of AF treatments remains suboptimal. Computational modelling of the atrial electrophysiology plays an increasingly important role in dissecting AF mechanisms and improving its treatments, but high computational costs often hinder the application of such models.

We propose three deep learning (DL) models based on fully connected and recurrent neural networks (NNs) to solve the Fitzhugh-Nagumo equations (FNE) and evaluate their potential for fast simulation of 0D, 1D and 2D electrophysiology models. In two of the DL models (recurrent and fully connected NNs), loss functions were based on the incorporation of FNE within its loss function, allowing the optimal combination of training data with physical constraints. Another recurrent NN was developed with a mean squared error (MSE) loss function as a baseline. All DL models use time and spatial coordinates as input data.

The training/test datasets were based on numerical solutions of FNE over T = 100 timesteps using the explicit finite-difference method. For 0D, 1D and 2D models, three datasets of Tx1, Tx100 and Tx10x10 pixels were used. The effectiveness and fidelity of the DL models were assessed using the MSE and the residual sum of squares (RSS). In 0D and 1D, similar performances in simulating action potentials were achieved for all three DL models with a general MSE of 10^{-2}, with RSS of 9.0×10^{-5} (0D) and 13 (1D). In 2D, both recurrent NN models succeeded in simulating a propagating plane wave and a rotating spiral wave, with MSE and RSS scores of 10^{-2} and 18.

The proposed DL models can be extended to higher dimensions (3D) to provide fast and computationally-inexpensive tools for simulating complex AF patterns.